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Spatial Orientation from Motion-Produced Blur Patterns: Detection of Curvature Change

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Report 1978-2

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Detection of Curvature Change

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When a craft departs from moving straight and level over a flat surface or when the surface is not flat, the motion-produced visual blur patterns that the operator sees change in terms of their curvature. It was demonstrated in a previous experiment that human observers are quite sensitive to blur pattern curvature, the present experiment tested whether observers could respond to blur pattern curvature change at a level of sensitivity that would allow them to detect corresponding changes in path
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of flight and in terrain height and therefore use these cues for improved orientation.

Two retinal loci were investigated (foveal and 30°-peripheral). Also to fully characterize the response to these patterns which flowed downward and also oscillated sinusoidally side-to-side, the display used three different vertical velocities (4, 8 and 16°/sec) and five different frequencies of horizontal oscillation (1/4, 1/2, 1, 2, and 4 hz).

The major finding was that with our electronically generated 16-element synthetic blur pattern display, sensitivity to curvature change was sensitive enough to be quite useful in assessing aspects of one's motion relative to the ground. The performance for the foveal-viewing condition was superior but the peripheral condition also indicated potentially useful sensitivity levels.

The results also indicated that slow-moving patterns were more effective bearers of curvature change information as were rapidly oscillating ones.

TABLE OF CONTENTS

INTRODUCTION

Blur lines are produced when either an observer or some elements in his visual field move too rapidly for the visual fixation reflex to operate. These lines blend during motion into patterns having a number of trajectory-related parameters that are readily processed by the human visual system. The parameters of blur pattern divergence and blur pattern curvature have been discussed previously (Harrington & Harrington, 1977; Harrington & Harrington, 1978). The topic of the current report is a third important parameter of high velocity orientation, blur pattern curvature change.

Blur pattern curvature accompanies virtually every departure from straight and level flight. All observer motions that are not straight and level produce blur patterns that have no straight blur lines at all; instead a vector field of curvatures uniquely related to the type of motion that produces it surrounds the observer.

The purpose of the experiment to be reported here, one of a series on visual blurring, was to measure human thresholds for blur pattern curvature change in order to determine where useable curvature change information can be found in the visual field under specific conditions of motion.

To illustrate the approach, consider the following example developed for the case of level flight with side-to-side oscillations superimposed on the forward motion. In this example the objective will be to project ground motion onto the visual plane corresponding to the display screen. Then we will predict where the various threshold curvatures found in the experiments can be seen in real flight.

The mathematical characterization is simplified if the ground is seen as moving beneath a stationary observer as shown in Figure 1. The coordinate origin is at the observer's eye. The ground is represented by the plane $z=-h$, where h is the observer's height. The observer's line of flight, or equivalently, the ground's motion toward him is parallel to the y axis and the lateral oscillation is given by $a\sin(bt)$. The observer's line of sight is shown by the vector $\underset{\sim}{d}$, determined by the direction cosines, $[dx,dy,dz]$.

The path of a representative element on the ground is shown with its component of velocity given by the vector $\underset{\sim}{c}$ and its lateral oscillation given by the vector $e(t)=[a\sin(bt),0,0]$. The head of vector $s'(t)$ traces out the projection of this element's motion in the visual plane. In the ideal case an observer cannot detect any differences

between the representative point on the screen and the projected point on the ground since both lie along vector s(t) and move in appropriate concordance producing identical loci of stimulation on the retina.

Thus the desired correspondence between experimental and actual visual stimulation is established. It remains to find the curvature of the path of s'(t).

Briefly, the lateral, forward and vertical components of s(t) are given by [asin(bt),vt,-h] where v is observer velocity. Vector s' is established by dividing s(t) by its own magnitude to unitize it and then multiplying it by the magnitude of s'(t) which is given by dsec theta. D is the distance from the observer's eye to the viewing screen. This angle between the two vectors is given by the dot product of vector d's direction cosines with the unitized vector s(t).

DESCRIPTION OF THE EXPERIMENT

Subjects

All ten subjects were students at the University of Nevada, Reno with normal visual acuity. All subjects were paid for their participation.

Procedure and Instructions

Subjects were run individually for five sessions, each lasting one hour. During the first session subjects were seated in a viewing booth 29 inches from a 5-inch diameter circular scope and familiarized with the two fixation points (central and peripheral--30° left) that they would use during the experimental trials. Subjects eyes were monitored to ensure their maintaining the appropriate fixation.

Each subject was familiarized with the parameters of the visual display and given the following instructions: "At the start of every trial you will see a pattern of moving elements on the screen in front of you. Say 'no', if the elements appear to be moving along a path with constant curvature; say 'yes', if the elements appear to be moving along a path with changing curvature. During each trial, a pattern of elements moving along a constant path may gradually begin to move along a changing path. As soon as you notice any amount of change, respond with 'yes'. A pattern of elements moving along a changing path may begin to move along a constant path. As soon as you fail to see contractions, say 'no'. Sometimes the pattern of elements will remain the same during the entire trial. Therefore, you must be somewhat certain that you notice a change before you respond."

In order to ensure that the subject understood the instructions, each subject was given ten training trials; a trial began when the subject, after fixation, made a judgment about the visual display and it ended when the subject changed his judgment. The starting point on the wheel outside the booth was randomly selected by the experimenter, and the subject determined whether it was an ascending or descending trial by his initial response.

This experiment was designed to measure the subject's threshold for detecting curvature change (threshold was defined as the mean "stopping point" or end response averaged over the ascending and descending trials) and to determine the effects of three additional factors (angular velocity, horizontal oscillation frequency, and fixation point) on the subject's threshold for detecting change. Therefore, during the experimental trials subjects were asked to fixate on either the central fixation point or the peripheral point (30° left) and to view the pattern of elements at one of three velocities (fast = 16 degrees/second; medium = 8 degrees/ second; slow = 4 degree[illegible]second) and five frequencies of oscillation (1/4 hertz; [illegible]ertz; 1 hertz; 2 hertz; 4 hertz). Thus, there were thirty e[illegible]ntal conditions. During the experiment each subject res[illegible] to twenty trials (ten ascending and ten descending[illegible] each condition.

Stimulus Generation

The stimuli were electronically generated and presented on an oscilloscope. Figure 2 shows the arrangement. In common synchronization with a digital clock a vertical sawtooth provided the downward motion of the trace, a 16-step generator provided the horizontal levels necessary for each of the 16 vertical sweeps to be positioned and a 32-step square pulse generator stepped through a memory that was loaded to provide one "on" location per vertical line, thus giving one element on each vertical line when the trace modulation was turned on. Divergence of the vertical lines employed in other experiments was induced by mixing some of the vertical signal with the horizontal signal so that as the trace moved downward its horizontal component increased to spread out the lines at the bottom. Curvature of the patterns, employed in a previous experiment, was produced by introducing a controlled amount of signal from a memory that had been programmed to give the appropriated magnitudes of offset, into the horizontal deflection. Curvature change was brought about by sinusoidally attenuating the horizontal curvature signal to the scope.

In the curvature change experiment the rate of pattern advance was variable, assuming one of three values under control of the experimenter. The frequency of sinusoidal

attenuation was also variable as was the threshold variable, amplitude of the sinusoidal oscillation horizontally. Subjectively the impression was of side-to-side motion imposed upon the downward flow of the elements as though one were looking at individual elongated bars on the ground below a helicopter flying a sinusoidal but level pattern. The element trajectories in Figure 2 are appropriate to designate the paths of the individual elements but in real time all of the elements would be seen flowing en masse back and forth left to right as they proceeded downward and all would have the same slopes at the same times.

RESULTS

Figure 3 and Figure 4 show the mean threshold values in peak-to-peak sinusoidal amplitudes. These were obtained for foveal and for 30-degree left viewing respectively at 16, 8 and 4 degrees per second of target angular velocity and for lateral oscillation frequencies of 1/4, 1/2, 1, 2 and 4 hertz. The associated data appears in Table 1. Viewing centrally decreases the threshold and lower angular velocities also result in lower threshold values.

The results of an analysis of variance are shown in Table 2. The effects of horizontal oscillation frequency, angular velocity and fixation point were all highly significant as were the interactions between frequency and angular velocity, and frequency and fixation.

DISCUSSION

The results indicated that the sensitivity of a moving observer to sinusoidal lateral oscillations of a blur pattern is, first of all, easily adequate to be useable for visual orientation, and, secondly, is improved if the pattern is fixated directly, in contrast to the case with many motion perception situations where the peripheral retina outperforms the foveal retina. In addition, faster moving pattern elements decrease sensitivity to lateral sinusoidal oscillation, but the loss can be compensated partly by increasing the frequency of lateral oscillation. In an applied situation, the angular velocity of blur pattern elements will be dependent on both craft or surface velocity and on altitude, since the angular velocity depends on viewing distance.

To illustrate the potential applied significance of oscillation sensitivity the following practical example is considered. It should be realized of course, that the laboratory investigations purposely employed pattern

Table 1

CURVATURE CHANGE THRESHOLDS FOR CENTRAL AND PERIPHERAL VIEWING (0.1 in.)

Central Fixation

Velocity (°/sec)	Frequency (hertz) 1/4	1/2	1	2	4
4	2.1	1.4	1.1	.8	.5
8	3.0	2.3	1.6	1.1	.8
16	3.8	3.0	2.3	1.4	1.1

30° Left Fixation

Velocity (°/sec)	Frequency (hertz) 1/4	1/2	1	2	4
4	2.8	2.4	1.8	1.3	1.2
8	4.0	3.0	2.3	1.8	1.4
16	5.3	4.3	2.8	2.6	1.8

Table 2

ANALYSIS OF VARIANCE SUMMARY SHOWING EFFECT OF FREQUENCY VELOCITY AND FIXATION ON CURVATURE CHANGE THRESHOLDS

SOURCE	SS	dF	MS	P
Frequency	67,662.12	4	16,915.53	<.01
Velocity	3,642.82	2	1,821.41	<.01
Fixation	2,160.62	1	2,160.62	<.01
Fxv	3,290.57	8	411.32	<.01
FxFix	1,442.77	4	360.69	<.01
VxFix	74.25	2	37.13	NS
FxVxFix	75.61	8	9.45	NS
Error	4,741.88	261	18.17	

parameters of an idealized nature to allow generalization to a wide range of motion types. Since sine wave motion was used, these results can be extended to complex motion situations through fourier techniques. For simplicity, this example will use sinusoidal motion and in addition will consider only level flight over flat terrain in order that the patterns of the example correspond most closely to the experimental display. For those who wish to represent other cases, the parameterization of the visual or display plane, to be outlined in a subsequent report, can be used together with any simplifying assumptions such as local curvature change homogeneities of the field of actual blur patterns that are dictated by the specific applied situation.

A pilot moving at 190 miles per hour 1000 feet above the terrain will have a relative angular velocity of 16°/sec since $w = (V\sin\theta)/d$ where V is horizontal velocity, w is the angular velocity in radians/second, θ is the angle of regard and d his distance from the horizontal surface. If he looks directly below without seeing any of the potential reference lines from the aircraft's form, he will be able to detect side-to-side one-hertz oscillation, one cycle corresponding to about 280 feet of travel, produced either by the craft's or the surface's lateral movement or by the combined movement of both of them of about 124" in amplitude. In this context a specific question might be whether a pilot would visually detect potentially hazardous sideward effects on his craft of a cross-wind gust under some particular limiting conditions of visibility or of a cross-wind gust when general turbulence is disturbing his facility of orienting with his inner ear mechanisms or with proprioceptive cues. Then the expected abruptness and velocity of the cross wind would be combined with other influencing factors, especially the weight and cross-wind response of the craft, to yield the spectrum of frequencies inherent in the resultant lateral motion. The frequency response characteristics of the human required for an adequate response would be calculable and could be matched with the experimental results under the usual precautions for generalizing from the laboratory to the field. In particular, the human response characteristics to this kind of blur pattern information might be changed by differing types of visual texturing, by shifts in intensity or contrast, by attentional factors and by physiological variables. Also, it is not known at this time how linear the human visual system is in terms of summating the responses at several frequencies in this type of visual task.

Although the major thrust of the experiment was directed to the question of whether a human observer might be able to detect suprathreshold blur pattern oscillations that were potentially useful, it is theoretically interesting to speculate on the possible mechanisms and formal properties of this aspect of blur pattern perception.

There are several ways that a system for detecting lateral oscillation could work.

1. It could respond to the lateral position or velocity component of the motion.

2. It could respond to the acceleration or some higher-derivative functions of the motion or to the lack of them.

3. It could respond either to the curvature or somewhat similarly to the lack of straightness.

4. It could process relative slopes of the element trajectories and even absolute slopes with the reference being supplied by the gravity detectors in the inner ear and elsewhere.

5. It could do any of the above either by processing the retinal image or by processing some aspect of the tracking eye-movement related information.

6. Different systems for different ranges could phase in and out as the rod and cone systems do.

One question of importance is whether the visual system is responding to lateral motion information or to shape information from the blur pattern

If the lateral velocity or acceleration components alone were important, the frequency of oscillation could likely help determine threhsold since changing the frequency changes these components. An appropriate comparison is available in the data. If the frequency is doubled and the velocity also doubled, then the shape of the trajectory will stay the same, leaving the various curvatures unchanged. Figure 5 shows the reactions between frequency and velocity that exist.

Figures 3 and 4 offer 16 pair-wise comparisons pertinent to this point. For instance, if one drops down from some point to a lower angular velocity curve and moves leftward to a lower frequency, then the new point will represent the same sinusoidal trajectory together with its curvatures, etc. as the starting point did but the path will have been traced twice as slowly with only half the horizontal oscillation frequency. Thus if the horizontal acceleration component of movement <u>per se</u> is being utilized the threshold at the second point should be higher; however, a sign test on the 16 possible comparisons is not significant indicating that this component is not being utilized and that trajectory shape may be the primary factor. If blur line curvature at threshold were within the human range for detectability then trajectory

shape would be a possible cue.

The lengths of the blur line segments are determined by velocity and intensity among other things but these determinations vary widely from individual to individual; however, blur lines in the current experiment usually were perceived as being on the order of 1/2 inch in length. If this figure is used to compare data with data from a static line curvature experiment (Pettee, 1978), sponsored by this laboratory, relating curvature detection to element length where the threshold radius of curvature was measured, calculations show that the curvatures present in our sinusoidal trajectories were comparable in magnitude to threshold values of the previously reported curvature experiment and in the range of those used by Pettee and by Valle (1956). Thus, it is evident that curvature per se cannot be ruled out as a factor since the maximum curvatures seen by our subjects at threshold were well within a detectable range.

Also a possible candidate for the discrimination variable is the slope of the trajectory. Our threshold stimuli did exhibit both relative and absolute disparities of an order of magnitude that would be discriminable but the present experiment was not designed by answer these questions; thus more work of a parametric nature is needed to clarify these issues.

Unlike the patterns in some of the previous blur pattern experiments (Harrington & Harrington, 1977; Harrington & Harrington, 1978), the curvature change displays appeared to lie in the plane of the display screen and showed only motion in that plane. There was no motion in depth as there sometimes is when accelerations are present as they were in these stimuli in the form of the sinusoidal lateral components of motion. On the basis of other findings our patterns might, for example, have looked like individual elements traveling down helical paths. Von Hofsten (1973) for instance found with a single moving spot that when the target was made to accelerate there was an appearance of motion in the third dimension and the target spot seemed to approach or recede. It may be that since the distances between element trajectories were relatively constant the appearance of a flat surface at a particular distance was maintained. This latter mode of appearance would be predicted by Johansson's (1972) principle of minimum object change which implies that the perceptual tendency in a case like this is to see a rigid object moving in translation, neither stretching nor binding nor twisting as a helical pattern would be required to do. Johansson notes that the principle may not hold up for complex arrays such as these. In a later blur pattern experiment discrepancies are noted but here the principle works.

The Gestalt grouping principle of common fate which tends to unitize figures should also operate in this experiment since all of the elements move together like a school of fish unlike the elements in the divergence change experiment.

It can be seen from Figures 2 and 3 that sensitivity to lateral oscillation of the patterns in both the fovea and in the periphery increases both as the oscillation frequency increases and as the velocity decreases. This probably is due, at least in part, to the fact that the sinusoidal trajectory curvatures in each case became greater even though the lengths of the curved segments decreased (and the data of Pettee and of Valle indicate that shorter lengths could decrease sensitivity). Another possibility comes from the experiments of Brown & Voth (1937) and of Hayoshi (1973). They find that when observers occularly pursue a circularly moving light the apparent size of the circle becomes smaller (and hence the curvature increases) as the light moves more slowly.

Recent advances in single-cell electrophysiology have led to the discovery of a large number of potential motion detectors, direction of motion detectors, slope-of-line detectors, wave length detectors, curvature detectors and curvature change detectors. It is tempting to invoke these neural units as units of explanation in this experimental setting; however, the respective sensitivities of these units to the parameters involved appear too low both in the experience of the senior author in observing such units and in the experience of other investigators (Heggelund and Hohmann, 1975) working with single neural units in the cortex of the cat found responses to edge curvature change in 14 out of 20 "simple cell" units from which they recorded. They found that the "tuning" of the units was very broad and state that individual cells in area 17 of the cat cannot detect curvature change at a perceptually significant level of sensitivity, nor can they adequately detect straightness. Thus it would appear that speculation about the neural underpinnings of curvature change detection in these experiments based on individual curvature processing units, at least generalizing from the cat, is futile. Similarly any explanation based on differential slope as the key to curvature detection faces essentially the same problems. Dow and Gouras (1973) working with anesthetized Rhesus monkeys found that sensitivity to slope changes of moving slits of light were on the order of 15-20°. Again this order of magnitude is far too coarse. It appears that the actual mechanisms of curvature change differential slope detection require cooperation from large pools of neurons or are based on currently unsuspected tuning or filtering mechanisms.

The data plotted in Figures 3 and 4 show that off-fovea viewing raises the threshold for curvature change. This is not surprising since a number of visual functions such as acuity that are possible curvature detection candidates also drop off in sensitivity peripherally. The surprising fact is that curvature change thresholds do not actually drop off very much in comparison with some visual functions, acuity for example. The acuity threshold for 30° left is down considerably, whereas curvature change has fallen off considerably less. This is in line with the fact that for certain types of movement thresholds and in critical flicker fusion under some conditions the fovea is at a disadvantage. This same lack of extreme difference between foveal and peripheral competence has been found in other blur pattern experiments (Harrington & Harrington, 1977) probably because blur patterns do involve aspects of motion and slopes of blur lines. This is a fortunate fact for the motion display designer who wishes to use the peripheral visual field more heavily.

Curvature Change Equations

$\underline{F}(t)$ is a position vector

$\dot{\underline{F}}(t)$ is the velocity vector (also tangent)

$|\dot{\underline{F}}|$ is the speed scalar

$\underline{t}(t) = \dfrac{\dot{\underline{F}}}{|\dot{\underline{F}}|}$ is a unit tangent to the path of $\underline{F}$

$$\dot{\underline{t}} = \frac{\ddot{\underline{F}}}{|\dot{\underline{F}}|} - \frac{\dot{\underline{F}}\,\overset{\cdot}{|\dot{\underline{F}}|}}{|\dot{\underline{F}}|^2}$$

$$K(t) = \frac{|\dot{\underline{t}}|}{|\dot{\underline{F}}|}$$

$$\dot{K}(t) = \text{Curvature Change} = \left(\overset{\cdot}{|\dot{\underline{t}}|}\,/|\dot{\underline{F}}|\right) - |\dot{\underline{t}}|\,\overset{\cdot}{|\dot{\underline{F}}|}/|\dot{\underline{F}}|^2$$

$$= \left(\dot{\underline{t}} \cdot \ddot{\underline{t}}/|\dot{\underline{F}}|\,|\dot{\underline{t}}|\right) - \frac{|\dot{\underline{t}}|\,\dot{\underline{F}} \cdot \ddot{\underline{F}}}{|\dot{\underline{F}}|^3}$$

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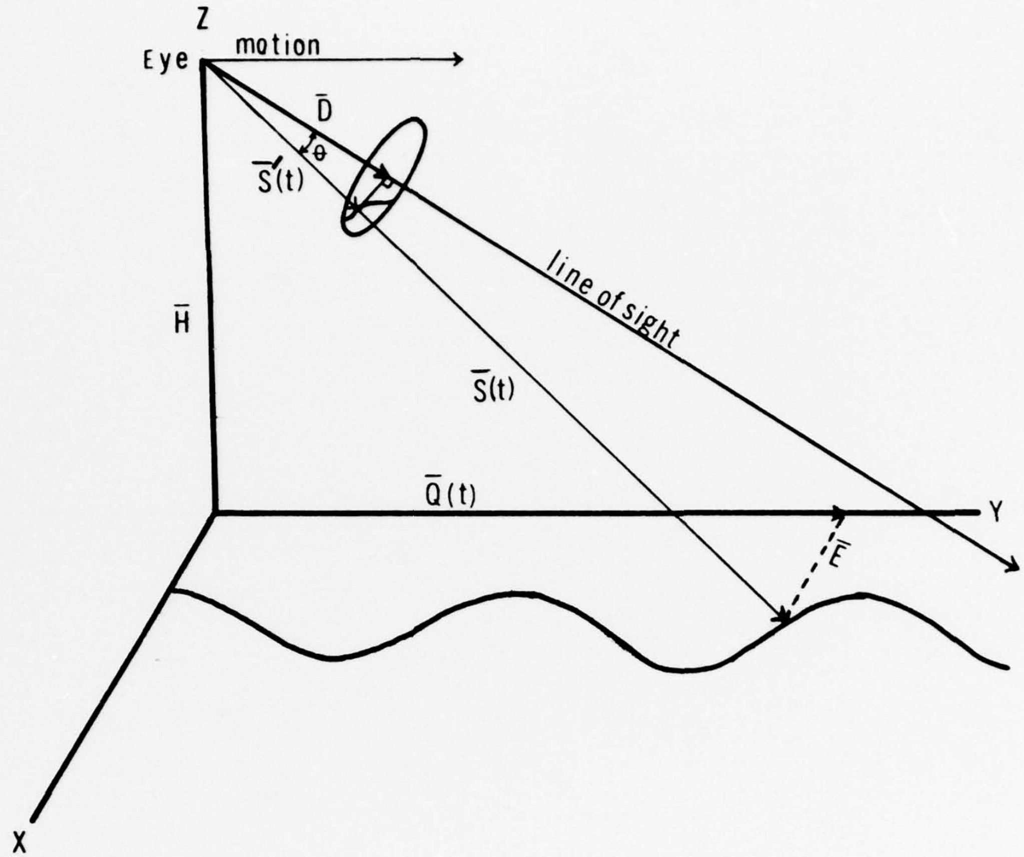


FIGURE 1

Geometrical characterization of blur patterns derived from lateral sinusoidal oscillation.

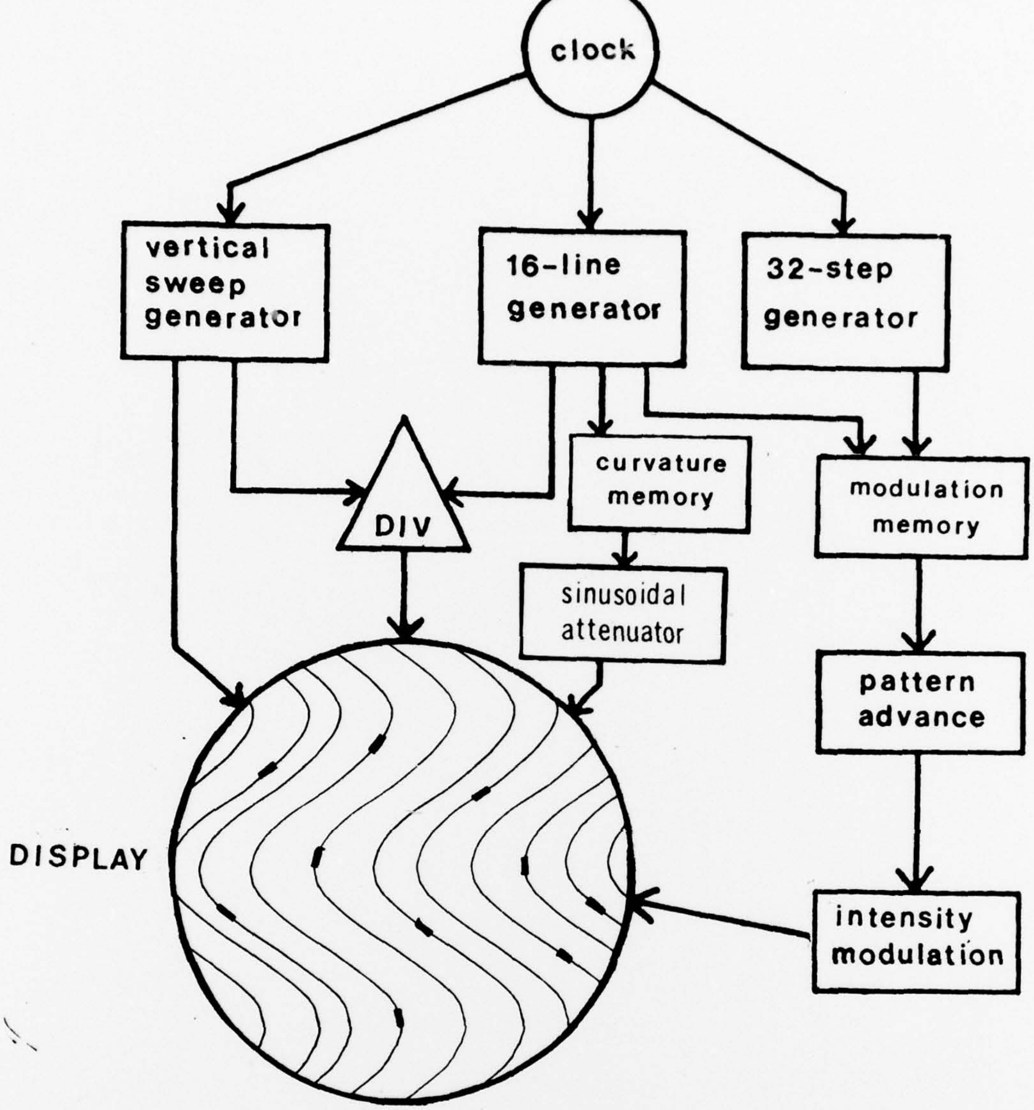


FIGURE 2

Schematic diagram of the synthetic blur pattern generator. In common synchronization with the clock, vertical lines on the display are produced by the vertical sweep generator, displaced successively from left to right by the 16-line generator and modulated to produce one element per line by the 32-step generator, the memory and the intensity modulator. Divergence is produced by mixing varying amounts of sweep signal with the horizontal displacement generator. Curvature change is produced by sinusoidally attenuating the curvature signal.

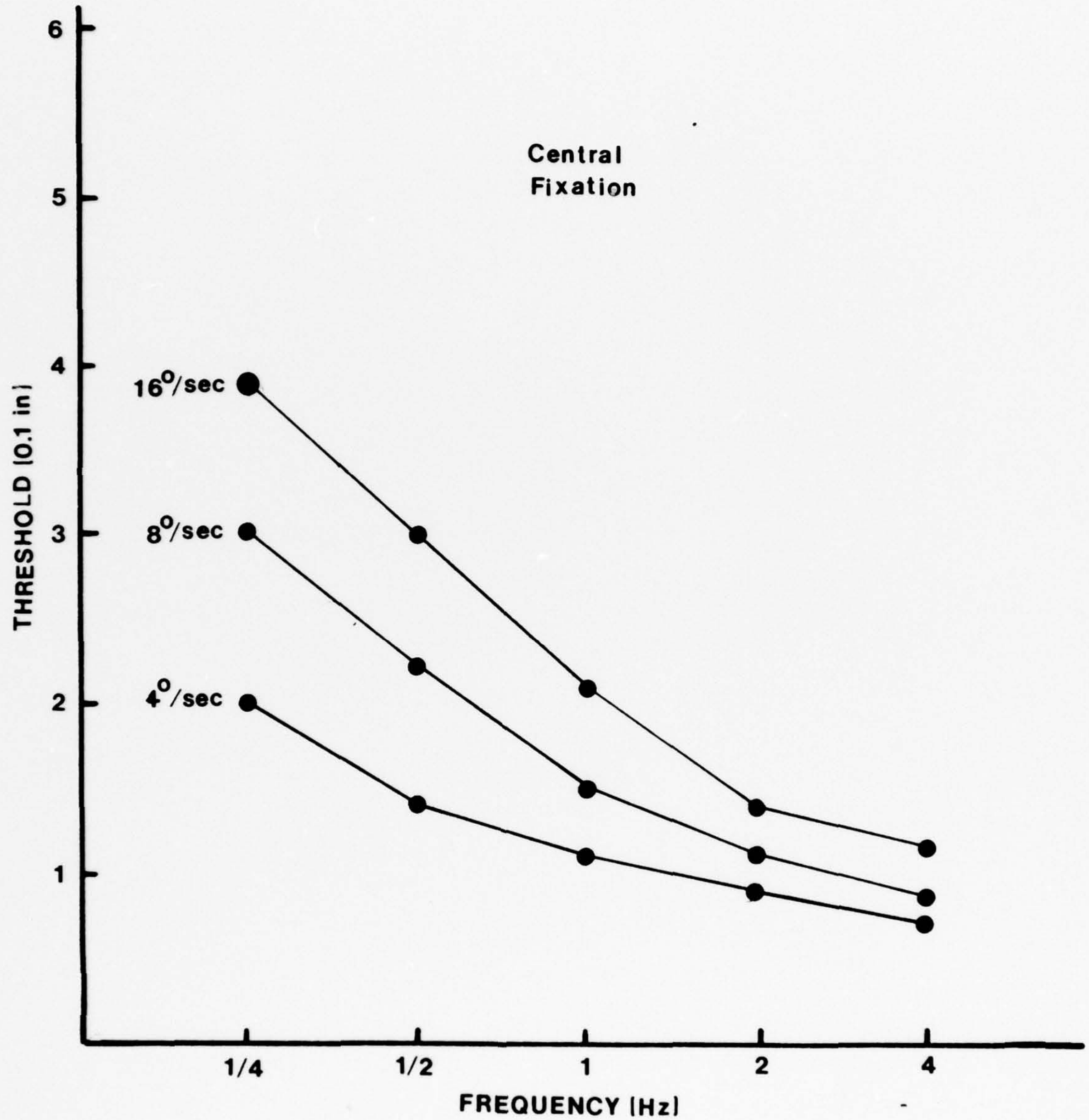
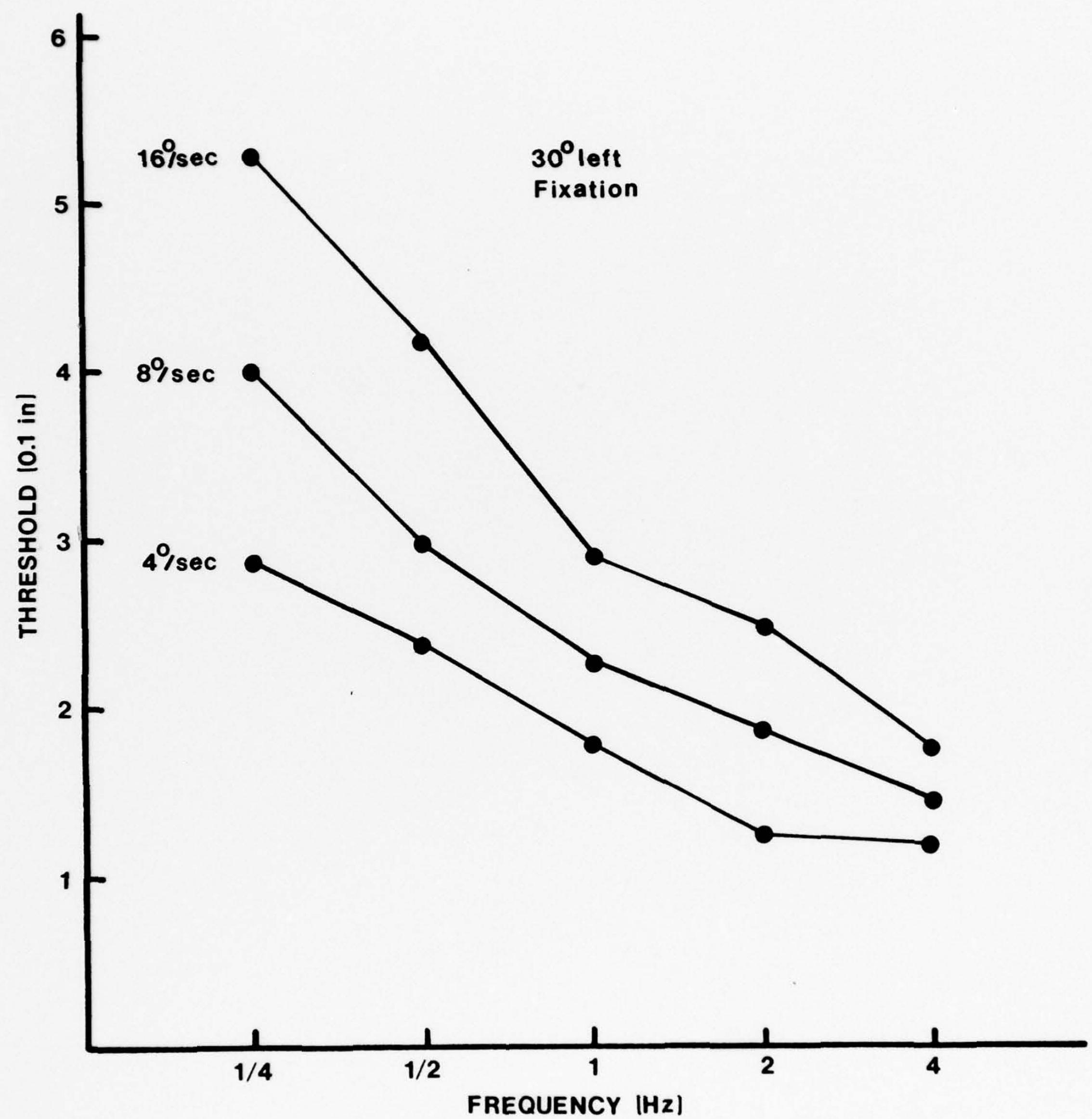

Central
Fixation
THRESHOLD (0.1 in)
6
5
4
3
2
1
16°/sec
8°/sec
4°/sec
1/4
1/2
1
2
4
FREQUENCY (Hz)

FIGURE 3



30° left
Fixation
16°/sec
8°/sec
4°/sec
6
5
4
3
2
1
THRESHOLD (0.1 in)
1/4
1/2
1
2
4
FREQUENCY (Hz)

FIGURE 4

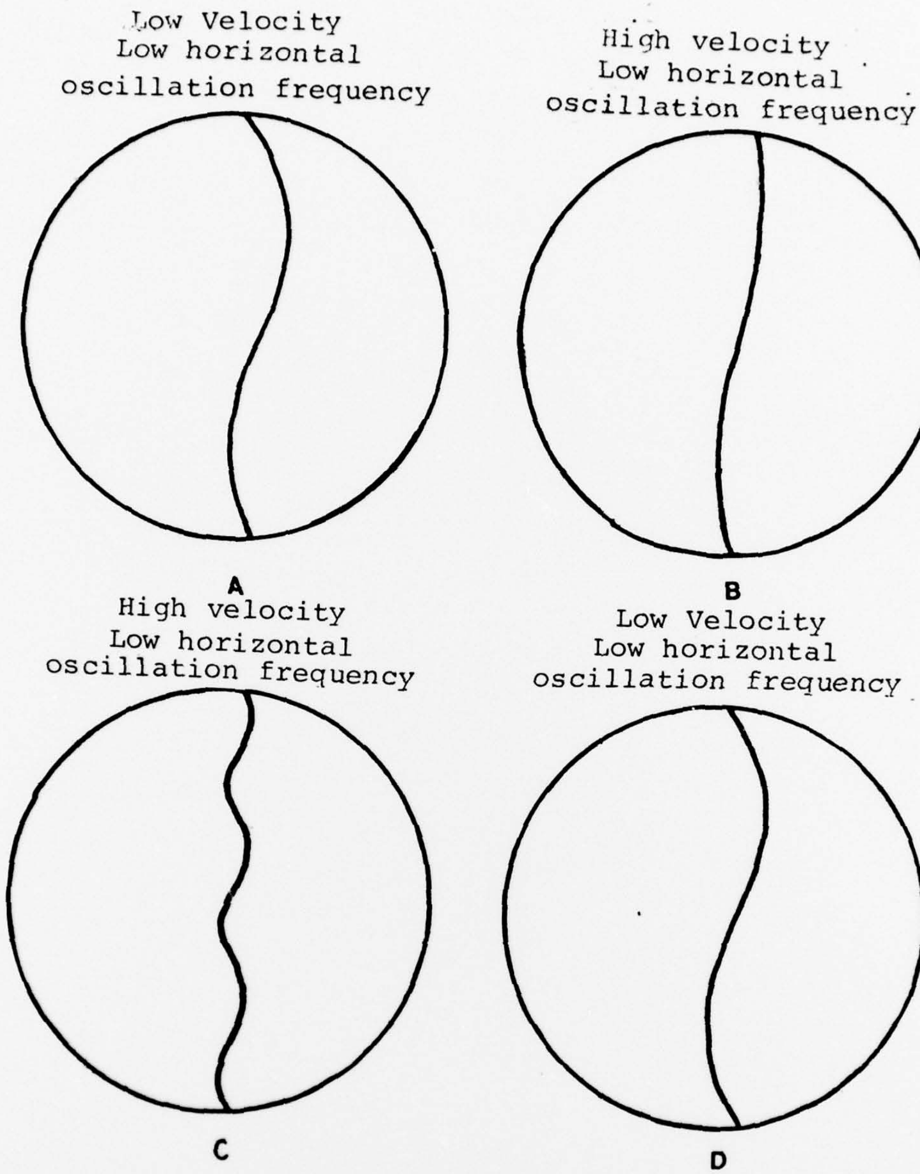


FIGURE 5

A representative set of curvature change stimuli representing different combinations of two vertical pattern velocities and two horizontal oscillation frequencies.

Note that the combinations in A and D produce the same trace but the velocity of element movement in D is higher.

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